LIGHTING RESEARCH PROGRAM

Project 4.4 Portable Office Lighting Systems

FINAL REPORT

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CONSULTANT REPORT

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

What follows is the final report for the Portable Office Lighting Systems, PIER Lighting Research Program Contract #500-01-041, conducted by the California Lighting Technology Laboratory under contract to the Lawrence Berkeley National Laboratory and directed by Architectural Energy Corporation. The report is entitled Portable Office Lighting Systems. This project contributes to the Building End-Use Energy Efficiency program.

The key deliverables for each project, in the form of guidelines and technical reports, are attachments to this report and are listed and described at the start of the attachment section. Due to market dynamics and the normal passage of time between the completion of research and the publication of research results, products anticipated for market delivery in this report may not necessarily reflect the actual array of products as delivered, or planned for delivery, by manufacturers. Therefore, the reader is advised to contact the lighting product manufacturers directly to ascertain the current status of products.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

EXECUTIVE SUMMARY

Traditionally, office spaces rely on ceiling-mounted luminaires for both task and ambient lighting. The target illuminance levels are dictated by task requirements, which results in uniform "task" lighting being provided throughout the workplace, i.e., even in places where it is not needed. This approach is inefficient because illumination levels drop by the square of the distance from the light source. Ceiling-mounted luminaires are relatively far away from the work plane, which makes them inefficient for providing task light when compared to task light luminaires, which are located closer to the work plane. The standard approach is also inefficient because task lighting is provided in non-task applications.

Separating task and ambient lighting systems can result in significant energy and lifecycle cost benefits by reducing the light levels produced by the ambient system to significantly lower levels, and by providing separate lighting fixtures for task lighting. In addition, proper controls used with the portable fixtures can enhance the energy-efficiency benefits and provide lighting control at both the workstation- and office-levels of application.

This report describes the results of the PIER LRP project focused on portable office lighting systems, which involved the design and development of 13 prototype portable workstation luminaires (PWL) that met the design goals to:

- Satisfy all of the office and ambient lighting needs with portable fixtures
- Provide appropriate levels of task light for detailed tasks (50+ fc)
- Provide appropriate levels of ambient light for general tasks (20-30 fc)
- Provide the maximum level of user control and flexibility
- Provide the maximum level of energy efficiency
- Achieve a market-appropriate pricing point
- Achieve an aesthetically pleasing appearance

Working with the manufacturing partner and gaining input from utility staff and the lighting industry, the research team developed a portable workstation luminaire using an 80-Watt compact fluorescent (CFL) and an integrated occupancy sensor. This unit yields significantly lower power density than T8 systems, with savings estimates of about 40–50 percent in office applications. This totals about 3,750 GWh/year, or about 1200 MW of demand reduction. A key benefit of the personal workstation luminaire (PWL) is that it has little or no installation cost since it is a plug load and the overhead lighting could be easily disconnected. Additionally, the integrated occupancy sensors assure additional savings with little marginal cost.

The final product of this project is the production of prototypes by the industrial partner for a 2005 field test in Sacramento. The research team and the manufacturing partner will evaluate the results of the field test to identify product changes and commercialization potential. Of note, the PWL's current 80-Watt lamp configuration is thought to be too large for workspaces less than 100 square feet.

ABSTRACT

Traditional overhead, ceiling mounted lighting systems for commercial office spaces have serious drawbacks, both in terms of energy efficiency and lighting quality. Generally, these systems place high levels of illuminance throughout the space, wasting energy by putting light where it is not needed, and often hindering visibility with glare. Combining low-level ambient lighting with task light has been shown to reduce energy use while improving lighting quality in office spaces.

This report summarizes research to design, develop, and test prototype portable workstation luminaires, and then to implement lighting controls in these lamps that would provide both workstation and office-level lighting control. Thirteen workstation luminaires were designed that provide controlled task and ambient lighting and a prototype of the most promising concept was then fabricated and tested in the laboratory. Additionally, four control scenarios were developed to provide task and ambient lighting at the workstation and in the office. The new unit is projected to reduce California office lighting energy use by about 45 percent, totaling about 3,700 GWh/year, or about 1200 MW of demand reduction

BACKGROUND

LBNL researchers developed the original Berkeley Lamp, primarily, for home office and hospitality applications. After initial deployment, it soon became evident that the Berkeley Lamp was generating significant user interest and excitement in the office lighting market. Subsequent and larger deployment efforts were geared more directly toward the office lighting market in order to characterize the energy savings potential and user response in offices.

The field deployment studies indicated that the Berkeley Lamp does, in fact, offer the potential to provide lighting energy savings in offices while simultaneously achieving widespread approval from users. Metering of more than 100 test sites over a period of many months indicated that energy savings of 40 to 60 percent could be expected when Berkeley Lamps were used. The test sites included private offices as well as small- to medium-sized open office areas. These savings were due jointly to the reduction of the overall lighting load in the offices (by turning off the overhead lighting) and by reducing the average hours per day of the lighting systems use. Secondary savings were also generated by the increased controllability of the lamps, allowing the users to dim the luminaires during operation.

Web-based surveys were distributed to many of the Berkeley Lamp users in the field tests and more than 100 responses were received. The primary focus of these surveys was to determine the user satisfaction with the new Berkeley Lamp-based office lighting systems. The results of these surveys were overwhelmingly positive with more than 90 percent of users claiming the Berkeley Lamps had increased the lighting quality in their spaces. To date, several thousand Berkeley Lamps have been have been deployed with the vast majority in commercial office environments.

Several critiques of the Berkeley Lamp were collected both in the "comments" section of the web-based surveys and in one-on-one communications. These comments covered a wide range of issues including aesthetic, photometric, and mechanical integration concerns. By far the most common request was for a "floor lamp" version of the Berkeley Lamp. This was primarily a response to the large Berkeley Lamp footprint making it difficult at times to place the lamp on a small desk. This would often result in the lamp being forced into whatever space it might squeeze into rather than being placed at the most photometrically optimal location. Users felt that a floor lamp version would provide added flexibility of location while freeing up valuable desk space.

In response to the user requests, LBNL designed and constructed several floor lamp versions of the Berkeley Lamp. These prototypes used identical optical elements (lamps, ballast, shade and septum) to the Berkeley Lamp, but instead of the top of the shade sitting 31" above the surface (i.e. the desk) it was positioned at 72" above the floor. This height was selected to match the height of standard torchiere lamps, which are designed to be tall enough to obscure their light source from most people in order to reduce direct lamp glare.

Additionally, the floor-based Berkeley Lamps were designed with integrated occupancy sensors that would automatically turn the lamps off and on in response to occupancy. Many of the Berkeley Lamps that were field-tested were installed with occupancy power strips (i.e. they were plugged into power strips that turned on or off in response to occupancy), which proved to be a very synergistic technology for the lamp. These strips further enhanced the energy efficiency of the lamp while giving the users an added level of automatic control.

Two Berkeley Lamp floor-lamp prototypes were cycled through a series of office spaces to assess their performance and potential user acceptance. These prototypes were placed both in offices where occupants had prior experience with Berkeley Lamps and in offices where occupants had no prior experience with table Berkeley Lamps. These deployments were not intended to serve as a formal field study, but rather to serve as an initial indicator of the potential of this approach. Feedback from these deployments was very positive. Users largely appreciated the lighting quality of these prototypes as well as the added flexibility that the floor lamp provided. Additionally, the integrated occupancy sensor was very well received and appeared to operate as intended, providing additional energy savings.

Results from the Berkeley Lamp research have been feed into the “super torchiere” effort under the PIER LRP Project 4.4 Portable Office Lighting Systems. This report describes the results of this work.

INTRODUCTION

Project Objectives and Team

The objectives of this project are to develop portable luminaires with integrated occupant controlled lighting technology to give the occupant direct control over his/her lighting system, to improve efficiency of office lighting technology by 30 to 50 percent and to improve cost effectiveness of office lighting technology by directing light to the areas where it is most needed. Building-level strategies were also determined.

This project has four key technical objectives:

- *"Berkeley Lamp II"*: Research and development of a prototype, next-generation Berkeley Lamp that integrates an occupancy sensor into a floor-based model.
- *Workstation Level Solutions*: Research and development of novel portable luminaires designed to provide for all of the task and ambient lighting needs of a cubicle or workstation in a manner than enhances energy efficiency and visual quality.
- *Office-Level Solutions*: Integration and controls strategies for the luminaires developed for the workstation level (above) that yields maximum energy savings while providing an appropriate overall office lighting environment.
- *Building-Level Concepts*: Investigation of broader building-wide systems/strategies that can build on the workstation and office level solutions in order to achieve further energy savings and control.

The project team includes:

- *California Lighting Technology Center (CLTC)*: project lead, develop portable luminaries and office-level control solutions[1]
- *Lawrence Berkeley National Laboratory*: develop building-level control concepts
- *Finelite*: work with CLTC to produce prototype portable workstation luminaires

Task/Ambient Lighting Design

Office spaces have traditionally relied on ceiling-mounted luminaires for both task and ambient lighting. Task requirements have determined the target illuminance levels, which result in the ceiling-mounted luminaires providing the equivalent of task lighting throughout the work space. This approach is relatively inefficient, since illumination levels drop by the square of the distance from the light source. Thus, ceiling-mounted luminaires used to provide task light are more inefficient than task lighting luminaires which are located closer to the work plane. Separating task and ambient lighting systems can result in significant energy and life cycle cost benefits by reducing the light levels produced by the ambient system and providing separate lighting fixtures for task lighting.

[1] LBNL staff began this project but the principal investigator left LBNL during the project to start the new CLTC so the project transitioned to CLTC except the building-level controls portion which was completed by LBNL staff.

Lighting with Portable Fixtures

While it is not common to see office applications where the spaces are illuminated entirely with portable fixtures, this approach presents some unique opportunities. The primary advantage to this approach is that it allows for the separation of the task and ambient lighting functions and thus enables the designer to achieve a true task/ambient lighting design. Portable uplights (i.e. torchieres) can provide the ambient lighting needs of the space, while portable desk lamps can provide task lighting.

There is an inherent flexibility in this approach that is missing in traditional ceiling-mounted systems. In addition to allowing the true task/ambient system to evolve over time, the system is flexible on a daily basis, allowing users to turn on or off a variety of lights and/or move the fixtures as needed.

This approach gives users the ability to put the amount of light they need where they need it and when they need it. It allows individual users in the same office the ability to control the lighting in their local environment that cannot be accomplished with traditional ceiling-mounted lighting approaches. This control ultimately leads to an increase in the overall lighting quality of the office and in the occupants' satisfaction.

Barriers to Portable Fixture Office Systems

Despite the energy savings and lighting quality improvements that can be achieved with the portable fixture office lighting system, there are factors that have kept this approach from being implemented. The largest barrier is that this approach requires new thinking on the part of lighting designers. Ceiling lighting is common and well understood, and building codes require certain levels of lighting to be installed for the building to pass the permitting process. It is also easy for lighting designers to specify a grid of ceiling fixtures, since this represents the traditional lighting solution for various building occupants.

In addition to these business-as-usual and social barriers, there are technical barriers to the use of task and ambient lighting systems. Primary among these is the fact that the portable fixtures on the market today are not optimized to fully provide the lighting needs of an office. While there are torchiere/desk lamp combinations that can be used with adequate results, none of them have been designed or optimized for a true task/ambient lighting system.

Lighting Controls for Portable Fixtures

The operation and control of individual portable fixtures that provide task and ambient light for a single occupant are straightforward. A more difficult problem is the integration of multiple fixtures in open office environments. The development of control systems and strategies that tie portable fixtures together into unified office lighting systems is necessary to realize the maximum energy-saving potential from task/ambient systems. While the control will be more complicated than the traditional wall switch for a ceiling-mounted system, it can be relatively simple for the occupants while still providing greater control over their lighting environment.

Project Approach

This project included three main efforts, as described below.

Prototype Development

The team developed conceptual designs and prototypes of portable fixtures that would be appropriate for task/ambient lighting in office environments. These designs and prototypes were developed through an iterative process in collaboration with Finelite Inc., the industry partner for this project.

Office-Level Controls

The vision of a portable lighting control system allows for a dynamic, automatic, and appropriate modification of a room's illumination as a function of changing user needs and room occupancy. This effectively translates to "putting light where it is needed, when it is needed." The research team evaluated a variety of approaches to achieve this broad goal and came up with a strategy to provide two levels of control: one for the task lighting and one for the ambient lighting, with ambient lighting including general and local components.

Building-Level Controls

Building on the workstation and office-level solutions, research team members investigated broader building-level systems/strategies to achieve further energy savings and control. This effort investigated the potential savings offered by broader centralized control features and the potential advantages they may add to this system through such features as addressability and load shedding. These control benefits can be achieved through various technologies, including DALI, UPB, IBECS, or Zigbee.

WORKSTATION-LEVEL LIGHTING SYSTEMS

Design of Workstation Fixture Prototypes

This phase of the research project focused on the development of conceptual designs and prototypes of portable fixtures that would be appropriate for task/ambient lighting in office environments. These designs and prototypes were developed through an iterative process, in collaboration with Finelite Inc., the industry partner for this project. There were three main design iterations where CLTC staff presented a series of designs to Finelite staff and considered their comments and suggestions for design refinement and development of new ideas. These three iterations resulted in the creation of over 100 luminaire designs and/or prototypes that could be broadly categorized into approximately 14 unique "families" of designs for task-ambient portable fixtures.

This section of the report presents these families of designs of the portable fixtures that have been developed. These designs are presented in a generic and uniform manner focusing on highlighting their unique features.

Most designs can be implemented using a variety of different light sources. To present these systems in a uniform way, the CLTC considered high-output twin-tube CFLs, which are among the most promising light sources that are available today. They are compact in size and offer high output and wide operating ranges. They are available in wattages ranging from 13 to 80 Watts. However, most designs can be adapted to use a variety of other light sources as well.

Design Goals

Early in the design process, a series of design goals were established in collaboration with the industrial partner. According to these goals, the portable fixture systems should:

- Satisfy all of the office task and ambient lighting needs with portable fixtures
- Provide appropriate levels of task light for detailed tasks (50+ fc)
- Provide appropriate levels of ambient light for general tasks, circulation (20-30 fc)
- Provide maximum level of user control and flexibility
- Provide maximum level of energy-efficiency
- Achieve a market-appropriate price-point
- Achieve an aesthetically pleasing appearance

Gamma: A Starting Point

At the outset of the project, Finelite prepared a portable luminaire design as a starting point for this new development project. While this design was based partially on initial "shared objective" discussions between LBNL and Finelite, the design was largely Finelite's creation. Finelite prototyped several of these luminaires and presented them to LBNL for analysis.

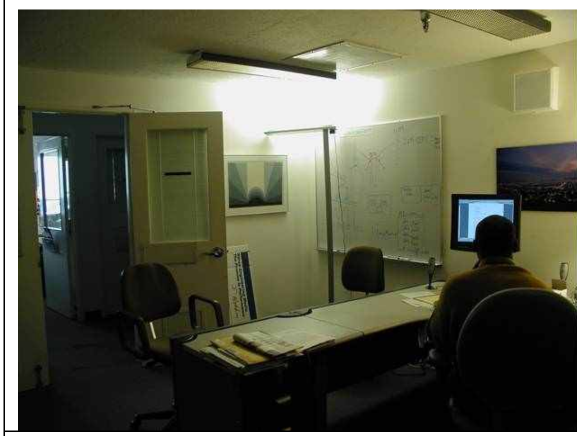
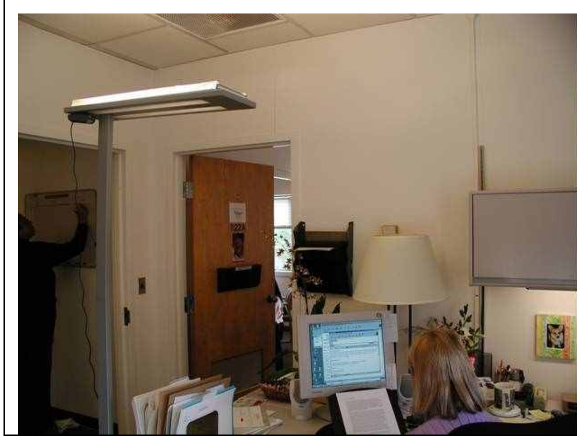
This initial design, dubbed “Gamma” after the similarity of its shape to the Greek letter (🗎), was a six-foot tall floor lamp with a sleek, rectangular optic head. The optical head housed two 50-Watt twin-tube CFLs, which were operated by a full-range dimming ballast. Most of the flux was directed upwards out of the top of the luminaire, but a small amount of flux escaped downward through a perforated metal reflector to provide direct task illumination.

While the functional and photometric characteristics of the Gamma design were studied, the primary focus was placed on determining the user response to the prototypes. This was done by moving these prototypes around to many different locations and different users, and allowing people to utilize the prototypes in their work areas. These test periods were generally one to two weeks, and included users that had previously been using traditional overhead lighting as well as users who had been using other portable luminaires, usually Berkeley Lamps. At the end of the test period, researchers informally interviewed the users to gather their impressions of the prototype.

Table 1 shows several pictures of these test applications along with specific comments from the users.

Table 1: A sampling of test applications and user comments of the Gamma prototypes.

	Pamela liked the fact that the lighting is mostly uplight. She felt that at the end of the day her eyes were less tired and strained. She liked the fact that there is no down-light glare and commented that placement seems to be very important as ambient light doesn’t cover the whole room. In her application, another uplight (Berkeley Lamp) was necessary to cover the entire workspace. She made a suggestion that the final model should have an incorporated motion sensor and (specifically) an incorporated sensor cord.
	Jeanne commented that the light from the lamp was too focused upwards instead of outwards, thus creating a hot spot on the ceiling above the lamp, and relative darkness in the rest of the room. She also noted that, while on the computer, there was some noticeable glare; when working off the computer, there was not enough downlight illumination.

	Cheryl had several concerns about the physical structure of the prototype (top heavy and cumbersome to move, etc.), but was generally pleased with the light output. She also didn't care for the aesthetics of the luminaire labeling it "too star-warsy."
	Calvin stated there needed to be serious revisions to the prototype. He felt strongly that the downlight component of the lamps was wholly inadequate.
	Nancy thought the color was very natural and had no problem with the intensity or direction. She felt the light was very diffuse, there was no glare, and she said it was comfortable for her eyes. She did mention that the lamp itself was very cumbersome and had awkward inertial properties. She said the shape of the lamp was odd and that it might be nice to have some way of directing the light.

While there was a great range of opinions from the users, overall the comments seem more positive than negative. Overall, people seemed to appreciate the level of ambient light and the quality of this indirect light, although some desired a wider spread. In applications in which some other room illumination was present (such as undercabinet lights or Berkeley Lamps), there was not a significant concern about the amount of downlight. But in applications in which the Gamma prototype was the only light source, this appeared to be a reoccurring concern. There were only limited concerns raised regarding glare issues.

First Iteration: Luminaires Providing Task, Ambient, and Controls

Based on the feedback from the Gamma prototype field tests, as well as significant prior user results from Berkeley Lamp field testing, LBNL initiated a concept development effort that built on the benefits of these two systems while addressing some of their shortcomings.

Immediately, it became clear that there would be a design dilemma because there were two critically important, yet often divergent design goals: maximizing the downlight component of the luminaire flux while minimizing the potential for glare. This dilemma was confronted by every design that was developed in this process and was addressed by a wide variety of methods.

The first series of design concepts were distilled down to the following five designs which were presented to Finelite in March 2003 for review.

Design 1: Up-Down Torchiere

The Up-Down Torchiere features an upper reflective element with a lamp (or lamps) as well as a lower reflective element with a lamp. The upper and lower elements are optically separated from one another and lamps within each element can operate independent of each other. This design is similar to the Gamma design in many ways, but adds a significantly greater level of downlight flux as well as the ability to independently control the uplight and downlight components. (Figure 1)

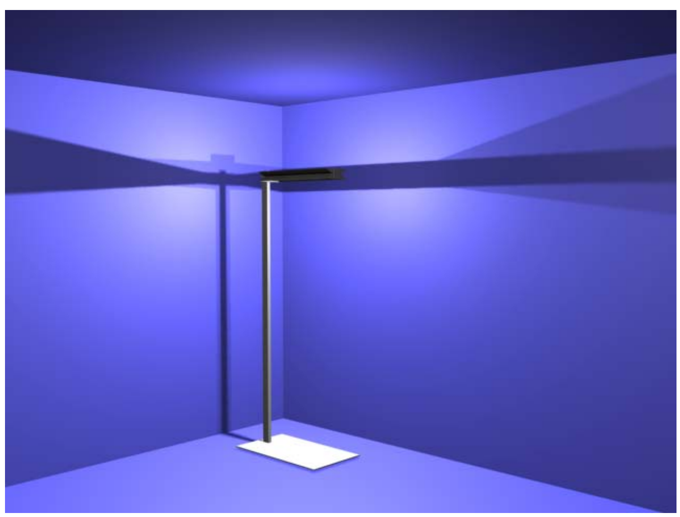


Figure 1: The Up-Down Torchiere Design

Design 2: Floor-Desk Duet

The Floor-Desk Duet consists of two fixtures, a task light desk lamp and an ambient floor lamp, that are physically separate, yet designed to work in tandem. The fixtures are aesthetically consistent in appearance and intended to share the necessary controls hardware for office level integration. This two-fixture approach allows for an additional level of freedom while partially addressing the maximum downlight versus minimum glare dilemma by allowing for a task light that is closer to the task plane. (Figure 2)

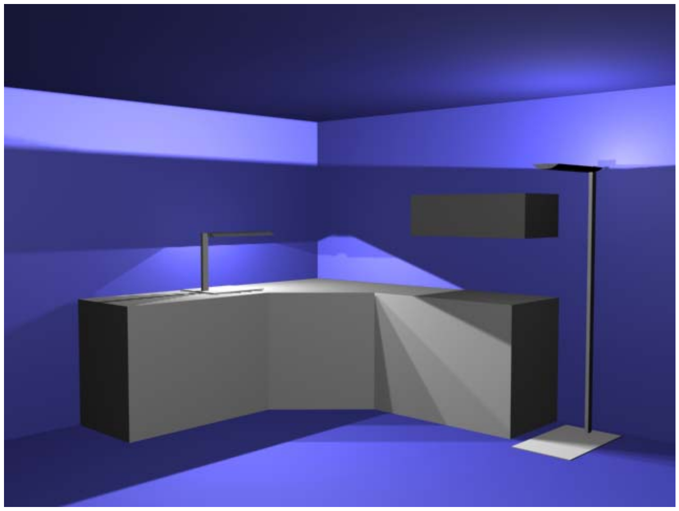


Figure 2: The Floor-Desk Duet Design

Design 3: Over-Under Cabinet

The Over-Under Cabinet consists of two fixtures, a task light undercabinet fixture and an ambient over-cabinet fixture, that are physically separate, yet designed to work in tandem. Much like the Floor-Desk Duet design, the fixtures are aesthetically consistent in appearance and also intended to share the necessary control hardware for office level integration. This design has the obvious limitation of only being applicable in applications with cabinets. (Figure 3)

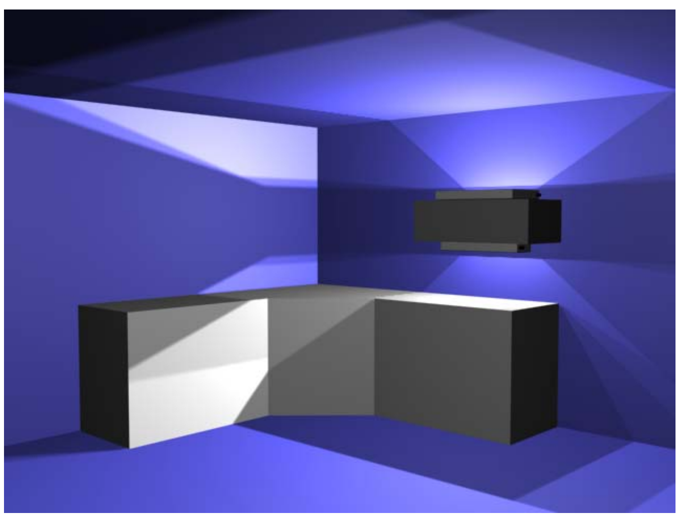


Figure 3: The Over-Under Cabinet Design

Design 4: Pole

The Pole design involves a single luminaire with two fully independent optical elements: a fixed uplight at the top and an adjustable task light mounted centrally on the pole. While these units are optically separated, their control features can be integrated. Functionally, this design is very similar to the Floor-Desk Duet design except that now the task light is mounted on the pole. This design frees desk space and allows the task light to be moved more readily to where it is needed, but requires that the pole and the uplight now be near the workplane. (Figure 4)

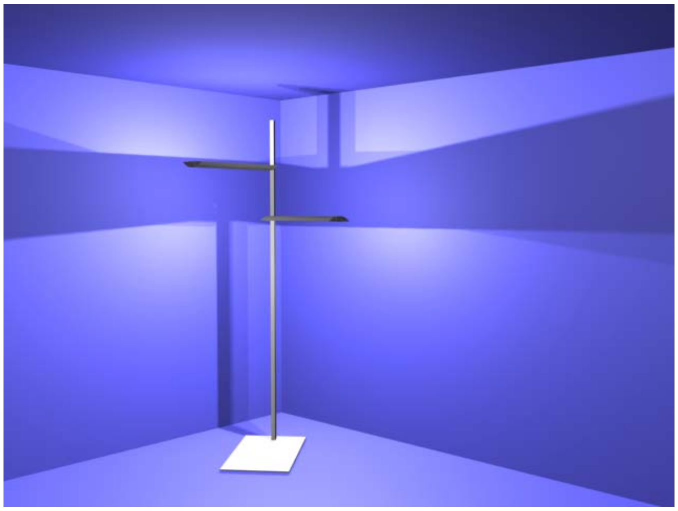


Figure 4: The Pole Design

Design 5: Barn Door

The Barn Door design consists of a central lamp surrounded by two rotating optical panels. These panels can be adjusted to provide 100 percent uplight, 100 percent downlight, or any combination between. This design is quite unique from those shown above. While the designs above all have static optical elements, the Barn Door design has moveable optical elements that allow its distribution to be dynamically altered to meet the changing needs of the user. (Figure 5)

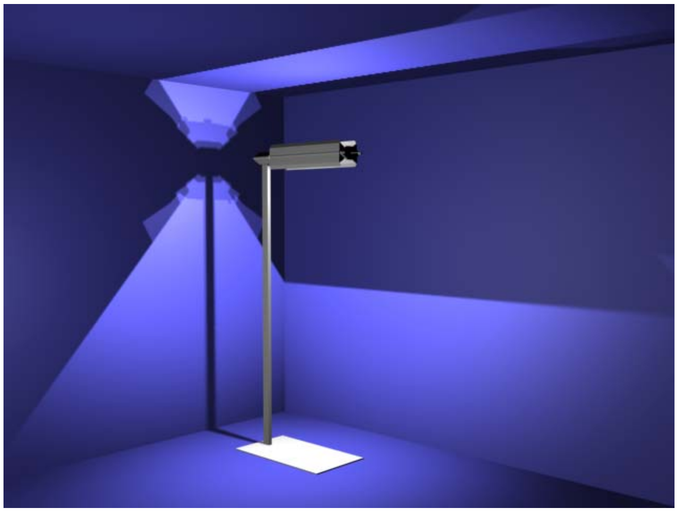


Figure 5: The Barn Door Design

Iteration #2: Barn Door Prototypes

Of these initial designs, Finelite expressed the most interest in the Barn Door design. There was some concern raised regarding the glare potential, but there was enthusiasm for the ability to dynamically alter the light output. LBNL was tasked to further refine and prototype this design.

Over the next few months, LBNL refined the Barn Door design and ultimately constructed several prototype systems. The most intricate designs included integrated servo motors that controlled the movements of the optical elements (Figure 6). These servos could be operated by the user via a push-button controller. A computer interface was also developed for the barn-door system that allowed the user to control the movements. From the computer, the user could move the optical elements into any orientation as well as define and select memory "pre-sets" for movement locations (Figure 7). Ultimately, it was thought that this computer interface could be tied into an "office-wide" controls system integrating a series of these luminaires into an open office.

Figure 6: Barn Door Prototype in downlight mode (left) and in uplight mode (right).

These prototypes and their associated controls systems were demonstrated to Finelite. Finelite was impressed with the intricacy of these systems, but had some concerns. One of their primary concerns involved the glare potential for the prototype when it was placed in its downlight mode. In this mode, the light sources were directly visible and Finelite recommended the use of a diffusing lens or baffle to mitigate this effect. Finelite also expressed some concern over the use of electronic motor systems in a luminaire, related to reliability and cost. They did not dismiss this approach entirely, but recommended the use of less complicated systems that could be adjusted manually by the users.

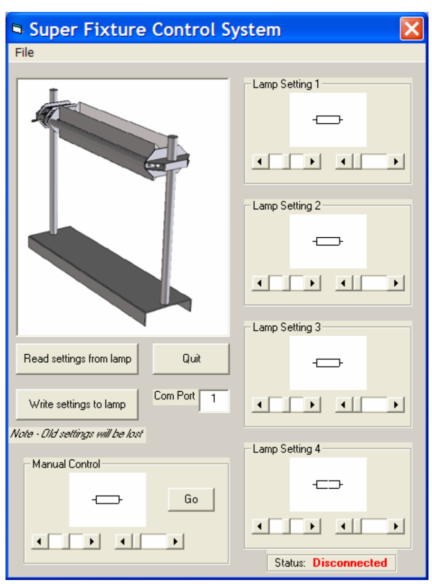


Figure 7: PC-Control Software for Barn Door Prototype

Iteration #3: Movable Optical Elements

Following this review with Finelite, LBNL continued to refine the Barn Door Prototypes, but also continued to generate a new series of design concepts. A large number of these new designs included Barn Door-like moveable optical elements, or MOEs.

There was a growing feeling by LBNL researchers that luminaires integrating MOEs presented some unique opportunities that should be considered in more detail. The MOEs could be either controlled mechanically by the users (i.e. the user pushes a lever on a luminaire that opens an aperture that increases the luminaire's downlight for task) or controlled by a variety of electrically driven devices (DC motors, servos, solenoids, etc.). While the mechanically controlled MOEs are generally more straightforward than the electrically driven MOEs, there are several advantages to the electrical systems. The primary advantage relates to the integration of lighting controls to these systems in a multi-person office.

In general, a typical lighting controls strategy would assume that when an individual cubicle is determined to be vacant, the luminaire in that room should either be off, or should be placed in its "ambient" lighting mode. With luminaires with mechanical MOEs, it may be difficult to determine what mode the MOE is in, and it is not possible to change the state of the MOE (i.e. to move the MOE from a task lighting mode to an ambient lighting mode). With electrically driven MOEs, however, once the lighting controls system has determined the cubicle is vacant, it can either turn off the luminaire or place it in an ambient light position.

There are other advantages of MOEs as well. One such advantage is the ability to generate actual or perceived dimming from a luminaire without the use of expensive dimming ballasts. This can happen with manual and/or electrically driven MOEs.

Limitations of MOEs relate to their potential costs and reliability. Clearly, these systems need to be very reliable. Their costs are related to the level of amenity and savings they provide. For example, if a user is interested in the MOE luminaires because of the energy savings they can expect by eliminating any unused task lighting in an office, the cost of the MOEs needs to be lower than the money saved from energy savings. Likewise, if the user is interested in MOEs for dimming, their cost needs to be below the cost of dimming ballasts.

The new MOE themed designs are shown on the following pages.

Design 6: Integrating Cylinder

The Integrating Cylinder attempts to provide a diffuse task light with the fixture's internal optical providing indirect illumination. In this case, two light sources are housed in uplight optics. The optics can either direct light into a central cylinder where it is redirected downward for task lighting, or they can direct the light outside of the cylinder for ambient lighting. This approach presents a low-profile package but at lower fixture efficiency than other alternatives.

Figure 8: The Integrating Cylinder Design

Design 7: Slider

The Slider design is modeled after a tradition rectangular uplight, but adds the ability to slide open an aperture on the bottom of the luminaire to generate downlight. This luminaire could be very similar to the Gamma design in aesthetic and profile, yet have the ability to dynamically alter the light distribution to meet individual users' requirements. (Figure 9)

Figure 9: The Slider Design

Design 8: Venetian Blind

The Venetian Blind design is very similar to the Slider design, except that the slider mechanism for opening and closing the task lighting aperture has been replaced with "venetian blind" style rotating optical elements. This approach has the potential to be mechanically more complex than the Slider design, but has an inherent advantage in that the blinds effectively become a louver when opened, serving to reduce glare. (Figure 10)

Figure 10: The Venetian Blind Design

Design 9: Pivot Control

The Pivot Control concept is similar to the Slider design as well. In this case, the slider mechanism is replaced with a single rotating "valve" that opens or closes the task lighting aperture. The dimensions of this aperture and the value can be optimized to maximum task illuminance while minimizing the potential for glare. This design presents one of the more straightforward mechanisms of MOEs. A relatively simple movement by an optical element has a great effect on the system's light distribution. (Figure 11)

Figure 11: The Pivot Design

Design 10: Flapper

The Flapper design involves a torchiere-style profile with a controllable task light aperture at the bottom/center of the luminaire. There are one or two flaps (depending on if they come from one side or both sides) that, when open, allow light to pass through the task aperture, and, when closed, redirect light upwards. The task aperture utilizes a diffuser or lens to mitigate glare. The flaps allow the user an added level of optical control, allowing them to adjust the task lights cut-off angles, re-orient the output for a wall washing application, or select a number of other effects (Figure 12).

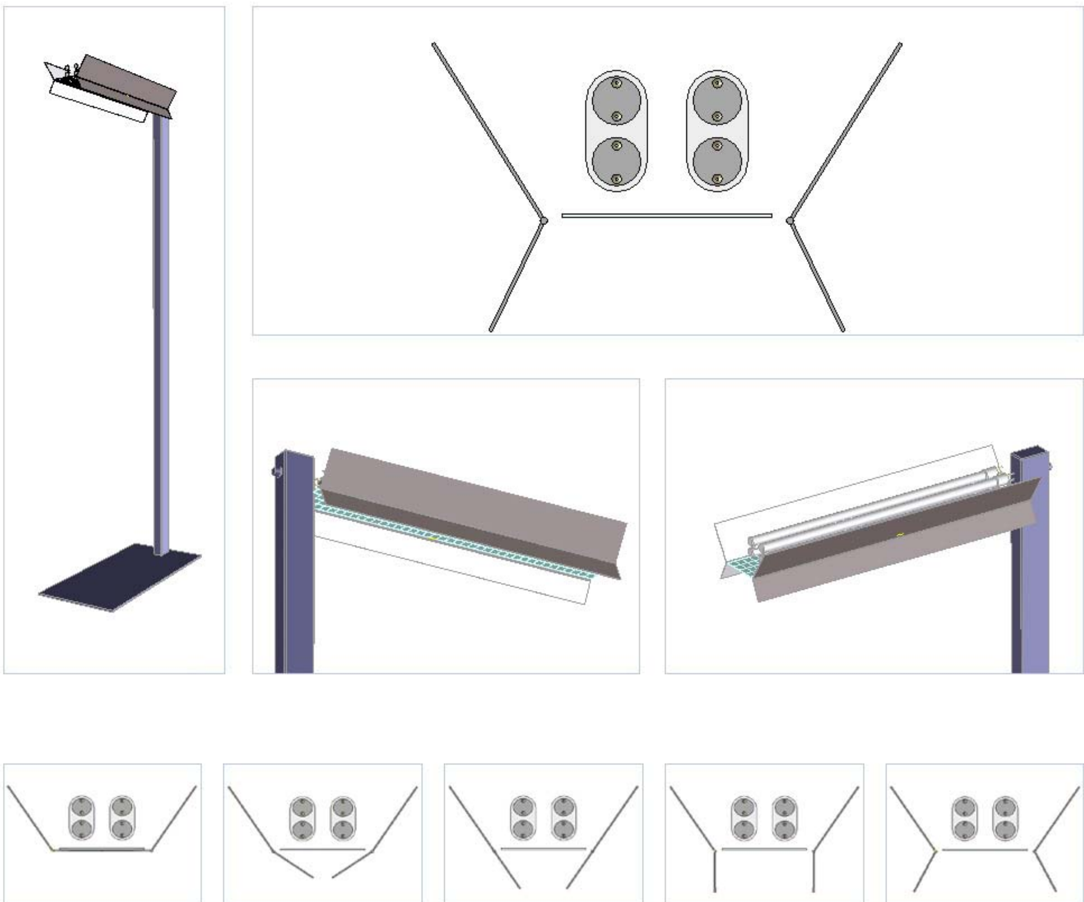


Figure 12: The Flapper Design

Design 11: Three Lamp Gamma

The Three Lamp Gamma design does not involve the use of a MOE, but rather aims to allow the user to control the distribution by selectively switching the fixtures light sources. This design borrows the aesthetic of the original Gamma Design (Table 1), but includes an internal optic that directs the output of two lamps upwards for ambient light and while utilizing a third lamp that is directed down for task light. (Figure 13)

Figure 13: The Three Lamp Gamma Design

Design 12: No Center Lamp Gamma

The No Center Lamp Gamma is designed to be functionally similar to the Three Lamp Gamma design, but do so in a luminaire that only utilizes two lamps for cost savings. This is accomplished by utilizing the same basic optic as the Three Lamp Gamma, placing lamps in the outer two uplight cavities and allowing lighting to leak into the center task light cavity through an adjustable aperture. The mechanism for allowing light to leak into the center element could be via a MOE. (Figure 14)

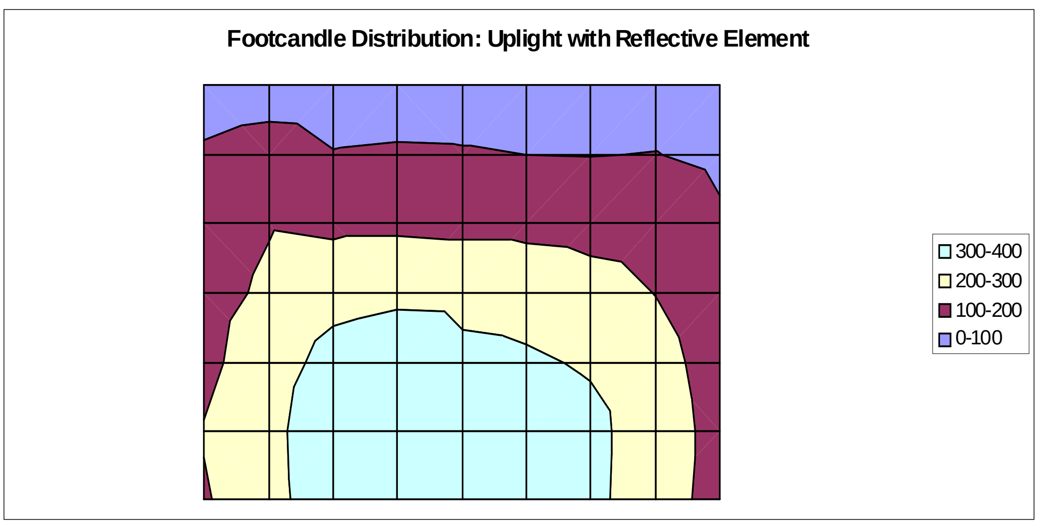
Figure 14: The Three Lamp Gamma Design

Design 13: Task Light, Ceiling Ambient

The Task Light Ceiling Ambient design was the final design that was proposed. This system is different from all of the others in that it utilized some level of illumination from an overhead ceiling lighting system to provide the ambient lighting element, rather than providing the ambient lighting system from the portable fixtures. At its most basic level, this approach could be as simple as delamping an existing overhead lighting system to a low ambient level and utilizing high-performance task lighting. A more advanced approach would involve an integrated controls system, likely built into the user's task lamp, which would allow the users to communicate and control the ambient lighting that particularly affected their work area. This system could also have a workstation level occupancy sensor that turned off the task light, and perhaps the ambient light, when the occupant was not present.

For many of the designs, it was clear there would be more than enough downlight illuminance and that the primary concern would be controlling downlight glare. But in some of the designs, such as the Pivot, there were some questions as to whether there would be an acceptable level of downlight. In such cases, it was necessary to construct optical prototypes to assess the performance of the design. This process involved measuring the task plane illuminance of the prototype fixtures and modifying the optical elements of the fixtures to optimize the light output characteristics.

Each of the 13 designs that are presented in this paper has been found to provide an acceptable level of downlight. In some cases, such as the Pivot, it was necessary to make modifications and optimizations to achieve these goals, but in the end, they were realized. Figure 15 (below, in two parts) shows an example of the photometric analysis plots that were generated during this modification and optimization process.



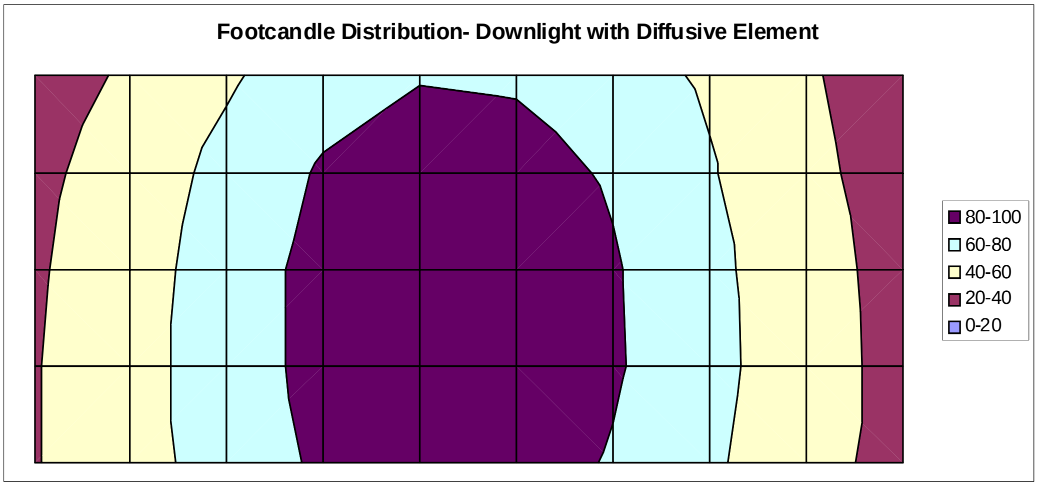


Figure 15: Example illuminance distribution plot measurement from optical prototypes

OFFICE-LEVEL LIGHTING CONTROLS

Overview of Controls Approach

The overall vision of a control system for a portable lighting system is one that allows for a dynamic, automatic, and appropriate modification of a room's illumination as a function of changing user needs and room occupancy. This effectively translates to "putting light where it is needed, when it is needed." When done properly, the result should be an increase in lighting quality and a decrease in energy usage.

Considering this control approach in combination with task-ambient portable luminaires, the broad vision is to provide an environment in which the ambient components of the luminaires in the room combine to create a uniform general ambient lighting effect for the space, while the luminaires' task components serve the local task illumination requirements. Given this vision, the first problem is determining the conditions under which the luminaires' task and/or ambient components should be turned on or off. Then, it must be determined how to turn these components on or off.

Two-Level vs. Three-Level Control

Through the development of the task-ambient lighting strategy and the refinement of specific prototype luminaire systems, the CLTC has established some specific strategies for the integrated controls of portable office luminaires. At the most basic level, these systems require two levels of control: one for the task lighting and one for the ambient lighting. However, it has been determined that there may be great added value in a system that provides three levels of control: task, general ambient, and local ambient.

Local ambient refers to an indirect (reflected) lighting that primarily illuminates the local environment. An example of local ambient is an open office application when users utilize torchieres (uplights), which have a fairly focused upward beam spread, to provide a controllable level of indirect light in their personal workspace. In this application, some of the flux from the torchieres reaches spaces outside the user's cubicle. However, because of the focused beam spread the effect of the luminaire drops off significantly outside its immediate area. This is in contrast to what is generally referred to as ambient lighting, in which a fairly uniform level of illumination is present throughout the space. The CLTC referred to this as "general ambient". The three levels of lighting for the control system to consider are task, local ambient, and general ambient.

In most applications, the task and local ambient components are best satisfied by portable luminaires. The general ambient, on the other hand, can be addressed either by portable luminaires or by overhead fixtures. The CLTC explored both of these approaches for general ambient illumination.

The initial focus of this research was on systems that provided two-level control solutions. These systems have certain advantages over three-level control systems. One of the main advantages of two-level control systems is they are potentially simpler and cheaper to apply. A two-level system may still be the best approach for private offices, but shortcomings of this approach begin to surface when considering multi-person spaces. It became increasingly clear that two-level control solutions often had significant limitations.

Initial resistance to adding a third level of control was due to concern over the added complexity this would bring to the control system. One of the primary goals of this project was the development of a simple lighting control system that would not require the type of commissioning by lighting professionals that is common on more complicated lighting control systems. As the CLTC examined this more closely, the addition of a third level of control actually simplified the controls equation by offering maximum energy savings with increased occupant acceptance. In such an approach, a general ambient lighting component (whether from the portable luminaires or the overhead fixtures) would be left "on" if there was occupancy anywhere in the space. This would ensure that a minimum low-level illuminance would be present in all occupancy scenarios.

Luminaire vs. Controls Solutions

There are many different avenues to achieve the three-level control. It is important to note this is neither purely a "luminaire" nor a "controls" issue, but really a combination of both. There is a continuum of possible approaches. On one end of the spectrum is a luminaire-heavy approach in which a portable luminaire is developed with three independent light sources: (1) a task light, (2) a focused uplight or broad downlight (local ambient), and (3) a broad uplight (general ambient). On the other end of the spectrum is a controls-heavy solution in which a control component is developed where different luminaires (task lights, uplights over various distributions) can be plugged in and automatically turned on or off. There is no simple answer as to how to achieve this level of control. The problem revolves around the integration of control and luminaire issues rather than a search for a luminaire solution or a control solution.

Discussion of Specific Solutions

Several control strategies are presented in this section, which describe and highlight the advantages and disadvantages of various approaches, as well as exploring in greater detail how these systems might operate.

1. General Ambient from Existing Overheads, Task from Portable Luminaire

<u>Luminaire requirements</u>: This case presents a task-ambient lighting system at its most basic level. In such a system the overhead lighting system is utilized to provide an overall level of illumination that allows for general circulation and other tasks which are not visually demanding. This is generally accepted to be in the range of 25-35 foot candles (fc). Task lights are then used at the workstation level to supplement the overhead lighting to reach levels appropriate for more visually demanding tasks, such as reading or writing. Fluorescent and halogen task lights in the 13-50 Watt range are often used in this scenario.

<u>Controls integration</u>: Because the luminaires used in this scenario are relatively basic, the control system options for the system are also fairly basic. Generally speaking, the vast majority of the energy usage from a lighting system such as this is from the overhead lighting system. This system should clearly be controlled by an occupancy sensor that automatically turns off the overhead lighting system when the entire office is no longer occupied. The task lights would be

controlled at a local level by the users, and may also be controlled by occupancy sensors (either luminaire integrated or power strip integrated). The cost effectiveness is dependent on the amount of electricity saved by using a lower wattage overhead system with energy efficient task lighting.

Discussion: This is the simplest solution and can easily be realized with technologies that are on the market today. While offices are generally not lit to these lower lighting levels (25-35 fc), they can be retrofitted, de-lamped, or re-lamped to achieve these levels. Occupancy sensors are typically connected to the overhead lighting in these applications, but could be readily added if not present. A wide variety of task lights are available for offices, including many fluorescent systems. The available task lighting generally has a relatively small area of influence. If users have a large area that they need to illuminate at a higher level, they may need two (or more) task lights. In applications in which significant areas require visual task performance (file cabinets, common areas with printers, copiers, etc.), this approach may be unworkable.

2. *General Ambient from Existing Overheads, Task and Local Ambient from Portable Luminaire*

Luminaire requirements: This scenario adds a third level of control to the two levels described above. In addition to the general ambient overhead lighting and the workstation level task lighting, a workstation level local ambient lighting system is also available. The local ambient is intended to provide general, indirect lighting uniformly in the local workstation environment. The local ambient system could have one of the following relationships to the task light: (1) fully independent from the task light (i.e., stand-alone torchiere uplight); (2) fully integrated with the task light (i.e., a luminaire with a fixed distribution that is partially uplight, partially downlight); or (3) partially integrated (uplight and downlight in same luminaire, but independently controllable).

Controls integration: Option (2) with the task light and local ambient light fully integrated is essentially a two-level control system analogous to the control scenario previously described. Options (1) and (3) are three-level controls that might require a new control scheme. In these applications, the user would have direct, independent control over the local ambient and task light in their area. A workstation level occupancy sensor can be connected to the local ambient and task light. Because there are now two light sources, the load connected to the local occupancy sensor will likely be higher than in scenario 1, thus making it more likely to be cost effective. As in scenario 1, the general lighting still must be on if there is occupancy anywhere in the office, so there is little advantage in tying the control of the general overhead ambient lighting system to the workstation-level control system.

Discussion: While very similar to scenario 1, this scenario has several distinct advantages. First, because individuals now have the ability to increase the ambient lighting in their local areas, it may be possible to decrease the general overhead illuminance even further for increased energy savings and reduced glare. General ambient lighting levels of 10-25 fc may be possible. Also, this system may be more generally applicable, as spaces that need larger areas with higher levels of illumination (common area for printers and copiers) can now have a local ambient luminaire at a maximum output level. The controls for this system remain relatively simple, with an occupancy sensor on the overhead fixtures and workstation-level occupancy sensors (working independently from the overhead occupancy sensor) connected to the task and local ambient luminaires.

3. General Ambient and Task from Portable Luminaire

Luminaire requirements: This scenario is quite different from the previous two, because overhead lighting is no longer considered. The task light is similar to the earlier examples, but the uplight component of the portable luminaire must be capable of providing enough flux to satisfy the general illumination needs of the office, approximately 25-35 fc. As in scenario 2, there are three options for integration between the task and the ambient light: (1) fully independent (i.e., stand-alone torchiere uplight and stand-alone task light), (2) fully integrated (i.e., a luminaire with a fixed distribution that is partially uplight, partially downlight) or, (3) partially integrated (uplight and downlight in same luminaire, but independently controllable). Option 2 is fairly limited from a control perspective as there is not much that can be done to this system aside from connecting it to an occupancy sensor. This solution is less than ideal as it may lead to circumstances when the ambient component of a system is turned off inappropriately when a cubicle is unoccupied, but the light may be needed by an adjacent space. Options 1 and 3 offer configurations with the flexibility to provide more creative control solutions.

Controls integration: This application represents great challenges and opportunities for control solutions. An overhead lighting system, which has been considered to have a single switch which either turns the lights in the entire space on or off, has now been replaced by several ambient luminaires which could be independently switched. This added flexibility creates opportunities, but presents challenges. On the most basic level, this system can be treated much like the overhead systems by tying together the operation of all of the ambient light components. Whenever the room is occupied, all of the ambient sources are turned on. While this would be relatively simple, this approach does not take full advantage of the added flexibility of the independently switchable ambient fixtures. For maximum energy efficiency, it would be advantageous to switch off some of the ambient sources when possible (for example, turning off several of the ambient sources on the northeast side of an office when only one person in the office is in the southwest corner).

Discussion: This system requires a level of integration that has not been required previously. Now that the specific general ambient sources are turned off, and it is important to know which portion of the room is occupied. The hardware infrastructure to make this determination is provided by the inclusion of local-workstation level occupancy sensors. At a primary level, these occupancy sensors can turn off the task light when the workstation is unoccupied. It is also conceivable that this occupancy information can be shared with the surrounding spaces affected by the light output of the ambient source so the system acts "intelligently". For example, consider a scenario where an occupant is in cubicle 1, while all of the other cubicles are vacant (Table 1). An intelligent and energy efficient solution would be to leave on the ambient sources in cubicles 1, 2, 4, and 5, while turning off the ambient components in cubicles 3, 6, 7, 8, and 9. This system can be modified for the specific needs of each application. For example, if the exit was located near cubicle 9, the ambient component of cubicle 9 might be left on if there is any occupancy in the space.

This type of intelligence now requires individual occupancy sensors (or their controllers) to "talk" to each other. This can be handled either with wires or, preferably, with a wireless system. There are a number of wireless systems and protocols, including emerging systems by the controls industrial partner, The Watt Stopper, which could be capable of offering this level of communication. In this scenario, a straightforward commissioning protocol is envisioned in which occupants define which ambient sources they would like to be "linked" to. This link could be made by running wires between the ambient source (or occupancy controller) and the devices to which they wish to link, or, with a wireless system, by entering the IP address (or equivalent) of the sources to which they wish to link. After these links have been established, if there is occupancy in a cubicle, the ambient component of that cubicle and all of the cubicles that the system is linked to will remain on. Consider an example where cubicle 1 is linked to 2, 4, and 9, while cubicle 7 is linked to 4, 5, and 9. If cubicle 1 and 7 were the only occupied cubicles, then 1, 2,4,5,7, and 9 would remain on while 3, 6, and 8 would be off.

Table 1: Occupancy State Diagram

1	2	3
4	5	6
7	8	9

4. General Ambient, Local Ambient and Task from Portable Luminaire

Luminaire requirements: This application is an extension of scenario 3, with a local ambient component added to the local workstation luminaire or luminaires. Again, no overhead lighting system is present and these various components (task, local ambient, general ambient) would be fully integrated, fully independent, or some combination. The general ambient lighting component will have a broad candlepower distribution, so it can be shared with the room as a whole. The local ambient will have a more narrow candlepower distribution, so it primarily affects the space in which it is placed.

Controls integration: The complexity of adding a third level of control to this application actually serves to simplify the controls of the system. This approach is very analogous to scenario 2, except now the general ambient component is provided by the portable luminaire rather than the overhead lighting system. Each workstation must have local occupancy sensors to turn off the task light and local ambient light when the workstation is unoccupied. When all of the spaces are unoccupied, then the system must turn off the general lighting components of all the portable luminaires.

Discussion: This scenario presents a very flexible system that should allow for maximum user control and enhanced energy efficiency. It represents a completely portable solution that could be integrated into a space that has no lighting or problematic lighting. It may represent an easier and potentially cheaper alternative to retrofitting the overhead lighting in a space if the users know that they only desire a low-level, general ambient lighting system. In this portable luminaire approach, the general ambient lighting systems would provide a uniform 10-25 fc whenever there is any occupancy in the space, while the task and local ambient controls could respond to the particular needs of the individual workstations. While the local ambient and task sources are controlled very simply by the local occupancy sensors, the operation of the general ambient components is more problematic. While these sources are powered separately at the various locations around the office, they need to be switched together. This can be achieved in a variety of ways, including communication between the local occupancy sensors (if any = occupied, stay on, if all = unoccupied, turn off), a central room occupancy sensor communicating via a wireless connection to the general ambient sources, or a central room occupancy sensor controlling a power breaker in which all general ambient sources are connected.

BUILDING-LEVEL CONTROLS

Introduction

The goal of this task was to investigate broader building-level systems/strategies that can build on the workstation and office-level solutions developed within the PIER LRP Project 4.4 Portable Office Lighting Systems in order to achieve further energy savings and control. This task investigated the potential savings offered by broader centralized control features and the potential advantages they may add to this system through such features as addressibility and load shedding. This section documents the results of LBNL's work in this area.

The workstation and office-level solutions were developed in Project 4.4 by the California Lighting Technology Center. In their work, the CLTC has identified a proprietary wireless networking system from the Wattstopper as the initial network candidate for their investigation. But to maintain the highest degree of generality, this report focuses on building-level systems and strategies and a multi-protocol gateway solution that is indifferent to the specific choice of lighting control/communications technique used to control the office lighting. The elegance of the IEEE 1451 intelligent gateway proposed in this report is that the overall building communications system should work regardless of whether the office lighting is controlled by DALI, UPB, IBECS, ZigBee or any other accepted communications protocol.

Context

LBNL researchers make the case for integrating office lighting control with building-wide environmental controls and show the application benefits of such an integration.

Control Strategies

At the office level, the goal of the lighting control system is to provide additional control capabilities to the occupants, and to implement localized control strategies such as daylighting or occupancy sensing for increasing energy efficiency. These strategies work locally, that is, all the "inputs" required for successful operation of the lighting system are obtained locally, at the point of use. "Global" sensor data acquired at the building level is not required or necessary.
In the work performed in the previous tasks, the CLTC has advanced the state-of-the-art by integrating occupancy sensing directly into each luminaire (rather than switching lighting at the switchleg level). This improved system works properly without additional global inputs.
But more control opportunities open up when one considers integrating local control with building-wide control and automation, which is the purpose of this report.

The successful integration of office and building level control systems can:

1) improve the demand responsiveness of a facility
2) improve lighting and building control operational efficiency by implementing daylighting and other sensor-based control strategies
3) eventually allowing lighting sensor data to help inform "intelligent agents" that monitor a building's sensor information for life safety applications.

Data can be collected from global sensors and from utility pricing signals to help make lighting, envelope and HVAC control systems more effective at exploiting available daylight or making building control systems responsive to power demand requirements. Integrating local lighting systems with building-level controls can provide occupancy status throughout a facility for life safety applications. In this advanced concept, an intelligent agent running on a network-connected server would analyze the occupancy status from multiple distributed occupant sensors to immediately inform an evacuation plan in the event of a building emergency (fire, physical attack, etc).

For example, to most efficiently implement demand responsive lighting requires knowledge of the real price of electricity going to the facility. This global input is not ordinarily available to a local control loop. Rather it must be supplied globally by the building automation or automated metering system that operates at the whole building level. In this load shedding scenario, the lighting control system would operate based on local sensors most of the time, but during power emergencies, local lighting loads would be shed (reduced in intensity either by switching or dimming) when commanded to upon receiving a signal based on the globally available cost of electricity.

Advanced control strategies such as daylighting generally use local lighting sensors to control overhead lighting in response to available daylight. But daylighting control system often can operate more reliably when local sensor information is supplemented by global sensor data, such as the external horizontal irradiance or illuminance.

According to the Commission's Demand Analysis Office findings, commercial lighting is 11-20% of peak electrical load in a typical commercial building. Considering that in the summer each 3 kW of lighting adds about 1kW of additional burden to the air conditioning system, lighting loads contributes about 4% indirectly.

In other situations, non-lighting systems (such as HVAC) may be able to operate more efficiently if they can acquire occupancy data from occupant sensors that normally control local lighting. In this case, a large HVAC zone would optimize operation based on an analysis of the actual real time occupancy as detected by occupancy detectors. For example, in addition to switching lights off where people are not present, occupancy patterns can be directly fed back to the HVAC use an economizer to modulate the fresh air intake rate in areas with low density or areas no longer occupied. The shades in unoccupied areas can be adjusted to cut off the direct sunlight, lowering solar heat gain. Of course, for this to work, the data from the occupant sensors must be available not only to the local light switch but also to a building-wide communications network that can in turn communicate with other building control systems.

Integration of occupancy, illuminance sensors, and imaging sensors with building control systems can yield tremendous non-energy benefits. Sensors that are useful for lighting control are also potentially very useful for life safety applications. If each office is equipped with an occupancy sensor and this data can be gathered, analyzed, and acted upon by an automation system, building life safety can be significantly improved.

The uniting theme is that if sensor information can be made globally available to any system needing that information, then building operation, efficiency, and life safety can be significantly enhanced at lower added cost since the basic sensors are already necessary for energy efficiency.

Getting double and triple duty from local sensors greatly improves the value proposition for advanced controls and goes a long way to justifying their added cost.

Intelligent gateway

The goal of the building level control system is to deliver amenities to each occupant without compromising energy efficiency and system integrity. Building level control system design, installation and implementation is an extremely challenging problem. Various trades are involved. A lack of knowledge in one area delays the completion of the project and has adverse effects on the performance of the entire system. The "intelligence" of the building control systems does not only come from clever use of sensory data for the development of control strategies, but also the intelligent decisions made during the design, integration, installation, configuration, and commissioning of each system. The cost of the systems can be greatly minimized if some of the initial labor-intensive tasks, such as the initial configuration and commissioning of the system are automated.

To integrate local lighting with building control systems requires adding networkable intelligent gateways to building automation systems. An intelligent gateway is a networking device much like WiFi routers that are proving so useful adding wireless connectivity to residential and commercial computer networks (LANs). Gateways are usually connected to the Ethernet on one side and to the local building LAN on the other. (For WiFi routers, Ethernet is usually provided on the gateway input and the output is the wireless LAN that interconnects all local computers and allows them to pass information to the Internet through the router.). In building controls applications, the Ethernet is also present at one end but the output will be a wired building control network (such as Modbus or DALI) or a wireless network (such as the ZigBee protocol).

The gateway is a necessary and critical component of a successfully integrated control system since it connects the Internet on one side to a building specific network on the other. Gateways are analogous to freeway interchanges. They allow cars (data packets in our case) to transfer from local roads (building-specific networks) to the freeway (the Internet) and back again. The difference is that interchanges merely transfer cars from one road to another – an intelligent gateway actually translates data packets from one protocol to another (for example from the TCP/IP protocol used for Ethernet to a building-specific network protocol).

In this report, a gateway that translates signals between device area networks (DAN) and building control systems is proposed. A level of intelligence is embedded so that the gateway framework can undertake configuration and commissioning tasks by recognizing the devices, their physical limitations, and their tasks. It is proposed that the gateways utilize Transducer Electronic Data Sheets (TEDS) to enable the building control system to detect and automatically configure sensors. This technology stores data sheets electronically. Thus, it eliminates manual data entry, improves accuracy with detailed calibration information, and reduces configuration time.

This framework relies on the adoption of IEEE 1451.2,3, and 4 standards. IEEE 1451 is a family of standards for connecting smart transducers to networks, which introduces the concept of TEDS. The application of this concept has not been expanded to the lighting sector yet and has been limited to industrial and environmental monitoring applications.

The following protocols and standards will be considered in this report:

IBECS 1-Wire	LBNL's application of an enhanced 1-wire network to lighting controls and building automation.
RF	New and emerging wireless networks that use radio frequency
PLC	Power Line Carrier (and other PL communications methods)
IEEE 1451	Standard for Sensors and Actuators
BACnet	Building Automation Controls

Overall Network Architecture

For the purposes of this analysis, the network is decomposed into three main segments titled:

- WAN – Wide Area Network, IP data network whose scope spans large geographic areas.
- LAN – Local Area Network, IP or data communications network whose scope is within the facility where the control system exists.
- DAN – Device Area Network, refers to the control network in which telemetry and control devices are installed.

The WAN segment of this hierarchy is not analyzed beyond the fact that it includes the Internet and obviously plays an important role in any communications network.

The LAN segment of the network is typically used for data communications and is the main communications infrastructure used by the system-wide building control applications. As such, these applications must communicate in some way with the building control actuators and sensors. This is done via gateways or routers that link the DAN networks with the LAN networks. The integration of the communications technologies between the LAN and the DAN is only part of what is required. In addition there must be some sort of semantic integration between the applications on the LAN and the devices on the DAN. This typically means that the data models used by the LAN applications must be consistent with the data models used by the DAN devices. Sometimes this can be accomplished directly between a LAN application and a DAN device by doing protocol translation, but often it is necessary to insert an intermediary agent such as a gateway that can perform some sort of data translation and mapping between the LAN application and the DAN device's interface.

BACnet is an emerging standard in the building automation industry for allowing control applications on the LAN to communicate and use devices on the DAN. It includes both semantic and protocol level support. Of particular note in the context of IBECS is the BACnet IP standard, which allows BACnet to operate over IP networks. BACnet IP allows BACnet applications running on the LAN to more easily integrate with the devices on the DAN via gateways and routers.

IBECS 1-Wire Networks

IBECS 1-Wire Networks are an adaptation of Dallas Semiconductors 1-Wire technology. Its main benefit is its low cost, and readily available and simple components. LBNL has done some useful research into extending its range and making it more robust. Before it can be commercially deployed, there still needs to be some additional research and field tests to determine its operating constraints and to develop best practices to reduce installation problems and costs. IBECS 1-Wire requires wiring and is probably best suited for new construction or major renovation projects.

DALI Networks

DALI was developed specifically for lighting control and has begun to gain acceptance in the lighting industry in recent years. Over the last year, the National Electrical Manufacturers Association (NEMA) in collaboration with the PIER LRP under Project 5.4 has been developing a controls "overlay" to the original DALI protocol that will allow control devices to peacefully co-exist on a DALI ballast network. DALI's main benefit is simplicity of design and industry acceptance by US ballast manufacturers. DALI requires wiring and is probably best suited for new construction or major renovation projects.

RF Networks

RF technologies hold the promise of lower installation costs and may be the best choice for retrofit applications. Certain types of devices such as occupancy and light level sensors would definitely benefit from the wireless aspect of RF technologies.

There have been a number of RF technologies developed recently that are potentially applicable. Some of the standards being developed include IEEE 1451.4, Zigbee, Bluetooth, and potentially UWB (IEEE 1451.3). Some of the more prominent developers of RF technology for control applications include Motorola, Philips, Dust Inc., Zensys, RFM, and Ember. The developments of the technology have focused on the following requirements:

- Low power consumption (multi-year battery life)
- Low cost (less than $5 per node)
- Low data rates (10k – 100K baud)
- Short range (10m – 100m)
- Ad-hoc mesh networking

To date, the most promising technologies revolve around 1451.4 and Zigbee with a large number of companies announcing support for these two complementary standards.

PLC Networks

PLC holds the promise of using existing power lines for communication and may be appropriate for both new build and retrofit applications. There are a number of companies that offer PLC technology for control applications including Echelon, ITRAN, Domosys, and PCS Lighting just to name a few. In addition, LBNL has done some useful research into using PLC for lighting control. Issues with current PLC offerings include a distinct lack of standards and the relatively high cost of the technology, which makes it difficult to justify for lighting controls. In addition, PLC tends to be unreliable and more difficult to use in commercial applications. The new PLC technology being developed by PCS Lighting holds some promise as being a low cost option for PLC communications and merits further investigation.

Routers and Gateways

Each of the devices in the DAN typically interfaces to the LAN using some sort of gateway or router. Routers typically move native DAN packets over LANs without doing any significant protocol translation or data mapping. An example of this type of routing can be found in EIA-852 that is a standard that allows the tunneling of DAN type packets over IP networks. BACnet has a similar standard that allows the tunneling of BACnet packets over IP networks. It should be noted that this is different than BACnet IP, which uses IP as the BACnet transport protocol.

The Role of 1451 and the TEDS Concept

IEEE 1451 is a suite of standards, each aimed at standardizing communications for smart transducers. The Transducer Electronic Data Sheet (TEDS) provides a standardized way to electronically document the capabilities of a device. This electronic document can be read by applications that wish to use the device and thus the capabilities of the device can be discovered at run time. In other words, the application can determine the capabilities of a new device *even if it has never seen the type of device before*. The TEDS concept, which is developed and refined in the 1451.0, 1451.2 and 1451.4 standards, provides a robust mechanism to identify and exploit the capabilities of all the control devices on the network. The fully developed TEDS consists of three components: the Basic TEDS, the Standard and Extended TEDS, and the User Area. As the names imply, the basic TEDS would be common to all devices of a particular class (say, occupancy sensors). The Standard and Extended TEDS would be more manufacturer specific and provide manufacturers with product differentiation. The User Area would store information local to the installation, such as the GPS coordinates of the switch, for example.

Ideally, the TEDS is embedded within the devices on the network. The requirements for embedding a TEDS in a transducer are quite minimal and it is expected that the devices that reside on these networks will be capable of doing this. It should be noted in this scenario that although these networks are currently not compatible with the electrical interface that was specified in the original 1451.2, there are efforts underway in 1451.0, 1451.2, 1451.4, and 1451.5 to support general serial and RF interfaces. The concept of a TEDS and its functionality is applicable regardless of the physical interface on the IBECS network.

DALI devices are very simple in nature and don't support the ability to embed a TEDS in the devices. Nevertheless a TEDS for the DALI devices can still be used, but in this case it would be embedded in a DALI gateway. Note that in this scenario, the STIM (Smart Transducer Interface Module) that would normally reside in the device resides in the gateway. STIMs that are implemented in this way are referred to as "Soft STIMs".

Note that devices with identical functionality on the DALI and IBECS 1-Wire, PLC, and RF networks can be represented in a common fashion to any applications that need to interface to both. The TEDS that exist in the DALI gateway can be created dynamically as devices on the DALI network are discovered. It is worth noting that the many attributes of the TEDS would be the same whether they resided on a DALI gateway or are embedded in the devices.

In addition to using the TEDS, it is possible to use the specifications from IEEE 1451.1 to expose an object oriented interface to the devices of the IBECS 1-Wire, DALI, RF, and PLC networks. IEEE 1451.1 defines the concept of a Network Capable Applications Processor (NCAP).

Within the NCAP are defined a number of software components including:

- A standardized 1451 interface that provides a common API for all applications that need to communicate with the DAN devices.
- NCAP Block used to provide the 1451.1 “plumbing”. This block facilitates communications between all the other blocks in the system. These are implemented with a Block type class.
- Transducer Block used to communicate to the various transducer communications channels in the system. In the scenario, there would be a transducer block for DALI and a transducer block for IBECS. The TEDS for the devices on a DALI network would exist within the DALI transducer block. These are implemented with a Block type class.
- Function Block for implementing local application level logic. These are implemented with a Block type class.
- Network accessible variables and parameters. These provide a level of programmability by applications. These are implemented with a Component type class.
- Network communications port. These provide access to applications on the LAN that want to communicate with the NCAP. These are implemented with a Service type class.

The transducer blocks provide means to communicate with the devices on the DALI and IBECS networks and the TEDS publishes the capabilities of the devices on those networks. The function blocks within the NCAP provide local logic and implement the object interface classes that allow applications on the LAN to access the functionality of the devices and the NCAP. The applications on the LAN can communicate with the NCAP using either a client/server (tightly coupled) model or by using a publish/subscribe (loosely coupled) model. Furthermore, 1451.1 provides a mechanism for the applications on the LAN to discover NCAPs and their capabilities. Examples of these applications include facility monitoring or HVAC control programs.
Also, note that the 1451.1 interface allows the integration of other 1451.1 capable devices on the LAN network.

Role of BACnet

IEEE 1451.1 provides a standard framework and mechanism for implementing object-oriented APIs, but what it lacks is a standard set of industry specific objects that would go even further in facilitating interoperability and application development. BACnet provides a simple set of pre-defined objects and is more prevalent in building automation than is 1451. There are an increasing number of applications and tools that utilize BACnet. In addition, Annex J of the BACnet protocol allows for using BACnet over IP networks, also referred to as BACnet/IP. Therefore it may be desirable to combine elements of BACnet and 1451 in a Unified Framework Gateway. The application object interface in the gateway is compliant with BACnet so that applications that speak BACnet can interface and use the functionality of the devices. Like 1451, BACnet supports the notion of both a tightly and loosely coupled interface. Also, the same 1451 transducer blocks and API can be re-used to provide a method for interfacing to the various DAN networks. As before, the TEDS provide for a way to discover devices and instantiate BACnet objects that can be accessed by the BACnet applications.

As a final scenario, it is possible to incorporate 1451.1 and BACnet into a common gateway. This would provide the maximum in flexibility and allow the integration of both BACnet and 1451.1 compliant devices over the IP network.

Conclusion

Many lighting control companies have robust local lighting control systems with functional strategies for the office level controls. What the industry lacks is the efficient integration of local controls with building controls and energy management systems in order to utilize sensory data. LBNL proposes a framework for a gateway with a level of embedded intelligence, linking various device area networks (DANs) to building control systems. The proposed gateway acts as a translator for DANs enabling them to talk to each other and with a building control system. Just like a PC recognizing a mouse as soon as it is plugged in, the gateway will recognize devices with embedded or virtual TEDS. This presents a truly "plug and play" capability for the building control systems. As a result, sensory data can be automatically calibrated, collected and utilized with minimal labor for effective and efficient building controls.

The mature market cost of the proposed gateway is not yet known. But current product suggest that $1000/bridge is achievable today with off-the-shelf components and wireless routers that are common today for computer applications do not have significantly lower capabilities than the $1000 product and are now available at $100 - $200. If it is configured so that it caters to commissioning, maintenance, and energy monitoring, its benefit from a mere energy saving equipment can be extended to reduction in installation and maintenance costs.

Future Directions

One of the main features of note is that most suggested gateway scenarios leverage 1451 to interface to the DAN networks in order to provide a consolidated API that can be used by other function blocks and LAN application interfaces in the gateway. Therefore, further work should concentrate on developing an appropriate version of this API for lighting control applications. Initial work should focus on the DALI and IBECS 1-Wire networks with RF and PLC to follow. The LAN application of choice should be based upon BACnet. The following are a brief survey of the tasks involved in future work.

- Increase involvement with the 1451 standards effort. More specifically, support the newly established JDDAC development effort, which combines 1451 with Java for data acquisition and control applications. Involvement in this effort will allow LBNL to leverage their work to implement a gateway.
- Choose a platform for developing and prototyping a gateway targeted for building control. Alternatives for this effort include the TINI bridge from Maxim Dallas Semiconductor.
- Design appropriate TEDS, function blocks, and APIs for the gateway.
- Choose a prototypical off the shelf BACnet application for testing.
- Develop a prototype hardware interface for the DALI and 1-Wire networks.
- Implement a prototype of the device STIMs and function blocks to provide the standardized API.
- Develop a BACnet interface block for the gateway.
- Demonstrate DALI and IBECS 1-Wire working with a BACnet application.
- Publish API specifications and reference implementation to encourage adoption.

MARKET CONNECTION ACTIVITIES

During the prototype development phase, the research team conducted informal workshops with staff from SCE, PG&E, & SMUD, as well as a design session with Finelite and lighting designer Jim Benya.

The research team also has publicized the project results in many ways, including:

- Demonstrate the PWL to hundreds of industry professionals during California Lighting Technology Center tours and industry meetings, including:
    - IESNA chapter meetings (October 2004 and January 2004)
    - BIRA[2] controls meeting (October 2004)
    - PG&E lighting seminar (November 2004)
    - Lithonia lighting controls seminar (December 2004)
    - EPA Energy Star staff (December 2004)
    - US Congressional tour with Alliance to Save Energy (December 2004)
- Demonstrate the unit at ACEEE's August 2004 Summer Session technology forum in Monterrey
- Discuss the project in presentations, including the Emerging Technologies Summit in San Francisco in October 2004.

Demonstration projects are described in "Next Steps" later in this report.

[2] Building Industry Research Alliance

CONCLUSIONS AND FINDINGS

Project Outcomes

Final Prototype

The product of this project is the design, development, and prototype fabrication of portable energy-efficient office luminaires that integrate occupancy-based controls to provide users with a higher level of control and visual quality than they currently receive from traditional overhead lighting systems.

The end result is a prototype office lighting system that includes an energy-efficient luminaire and a control system that operates each individual luminaire separately, but also integrates each luminaire's operation with other luminaires in the office to achieve the desired overall lighting effect.

Final Analysis

A cost-benefit analysis was conducted to determine which features were to be included in the initial production prototype systems. This analysis included weighing potential energy impacts against the added costs of luminaire components that would increase the initial cost of the luminaire. This analysis was based largely on prior research conducted at LBNL on the energy saving potential of task-ambient systems, as well as from pricing information from the industrial partner, Finelite.

After investigating several luminaire designs and considering costs and benefits, Finelite constructed a prototype luminaire based on a fixed task-ambient lighting approach. This luminaire initially included a 55-Watt long twin tube CFL and a movable optical head. Thorough photometric evaluations were conducted of the 55-Watt system to determine whether it could adequately illuminate typical offices. These evaluations were not conducted utilizing gonio-photometer and integrating spheres, as was originally planned, but rather by conducting illuminance and luminance mapping of the luminaire output in a 10′x15′ model office. This evaluation was considered to give the most insight into the expected illuminance levels that would be experienced by the end-user at the work surface.

Based on the results of the photometric analyses, the lamp was replaced with an 80-Watt long twin tube CFL and the luminaire was retested. The system with the 80-Watt CFL yielded 50 foot-candles on the work surface (versus 35 foot-candles for the 55-Watt CFL). At this time an integrated occupancy sensor was also added to the luminaire to maximize energy savings.

This final 80-Watt luminaire was also compared to a state of the art "super T8" overhead lighting system in a typical single office application. The results are summarized in Table 2 below. The 80-Watt luminaire yields significantly lower power density than the super T8, largely because it primarily illuminates the work surface to high levers rather than the entire office. Similarly Table 3 compares an open office layout with standard lay-in 2x4 troffers to a task/ambient system using the PWL.

Table 2: Private Office Comparison of 80W PWL to T8 Systems

125 square foot office	*T8 Lamps*	*80W PWL*
Number/type of fixtures	Two 2x4 fixtures	One portable luminaire
Number/type of lamps	Two 32W T8	One 80W Biax
Room Power	128 W	80 W
Power Density	1.0 W/sf	0.64 W/sf
Power Comparison	100%	64%
Occupancy factor	75%	75%
Total savings	Na	52%

Table 3: Open Office Comparison of 80W PWL to T8 Systems

Open Office	*Standard T8*	*High Efficiency T8*	*80W PWL*
Type of fixtures	2x4	2x4	1 PWL/desk[3]
Power Density	1.25 W/sf	1.0 W/sf	0.8 W/sf
Power Comparison #1	100%	80%	64%
Power Comparison #2	na	100%	80%
Occupancy factor	75%	75%	75%
Total savings comparison 1	na	20%	52%
Total savings comparison 2	na	Na	40%

In addition to the 20–36 percent electric load reduction, additional savings will result from the occupancy sensors turning off lights when workspaces are unoccupied. The researchers conservatively estimate workspaces are unoccupied 25 percent of the time, yielding total savings of 40–52 percent.

Benefits to California

As shown in the tables above, the PWL could save about 50 percent of the energy use in typical private offices. In open offices the PWL is estimated to save about 50 percent compared to typical current systems and 40 percent compared with high-efficiency systems. Taken together it is conservatively estimated the PWL could reduce energy and demand by 45 percent in office applications. California energy use for 2- and 4-foot fluorescent office lighting is estimated as 7383 GWh/year[4]. Therefore, state-wide potential savings would be about 3,700 GWh/year, or about 1200 MW of demand reduction[5].

A key benefit of the PWL is that it has little or no installation cost since it is a plug load and the overhead lighting could be easily disconnected. Additionally, the integrated occupancy sensors assure additional savings with little marginal cost.

[3] Assume 100 square feet per desk in open office layout.
[4] California Energy Commission GWh data from Martha Brook.
[5] Assume 3000 hours/year average usage.

Figure 16: The portable office lighting system includes a portable luminaire that provides both task and ambient light, has an occupancy sensor to turn off task light when not needed, and is integrated with other office lighting to minimize overall energy use.

Next Steps

The solicitation of feedback on the performance of the prototype portable fixtures and user satisfaction with them is extremely important. Once this information is available, the entire product team can make an informed decision on the commercial potential of the prototype, or what modifications must be made to the prototype to enhance its commercialization potential.

The recommended first step is to determine the marketability of the workstation-level system with occupancy control but no office-level control. This will minimize the cost of the fixture but maximize its energy-saving potential. In parallel with this step, the fixture design should be reviewed to consider lower wattage alternatives for small workstations. The 80-Watt unit is too big for spaces less than 100 square feet. An additional consideration is to revisit the fixture design option of having two lamps, one each for up- and down-light. This two-lamp option was initially dropped because of cost considerations.

After a manufacturer commits to commercializing the basic product, the next step could be testing the fixture with the full office-level control package for application in open-office architecture.

To begin achieving these next steps, the CLTC initiated a demonstration project of 28 units with SMUD at United Stationers in Sacramento. Although installation is not expected until early 2005, preliminary feedback from building occupants is very favorable with those not yet having the PWL wanting them ASAP! These prototype luminaires will include the 80-Watt lamps and occupancy sensors, but will not include the full office-level control system that was developed with The Watt Stopper.

The team is also planning to order additional PWL units for use in PIER's upcoming UC/CSU emerging technology demonstration program.